Physicochemical and Optical Characterization of Aerosol Fields from Coastal Breaking Waves

Antony D. Clarke
Department of Oceanography
University of Hawaii
1000 Pope Rd.
Honolulu, HI 96822
phone: (808) 956-6215 fax: (808) 956-7112 email: tclarke@soest.hawaii.edu

Vladimir N. Kapustin
phone: (808) 956-7777 fax: (808) 956-7112 email: kapustin@soest.hawaii.edu

Award Number: N000149610320
http://pali.soest.hawaii.edu

LONG-TERM GOAL

Our long term goal is to establish an improved understanding of the properties and factors that control the surf zone aerosol generation processes, their dependence on oceanic and environmental conditions and aerosol evolution in transition from pure marine to coastal environment.

OBJECTIVES

Our intent is to establish an understanding of and a predictive capability for the size distribution of aerosol produced under various conditions, their 3-D spatial structure and associated optical effects. The basis for our studying is the relation of coastal aerosol optical properties and spectral visual range to the aerosol produced from breaking waves and its response to various environmental factors. Our hypotheses are:

A. Variation in coastal atmospheric optical properties including their near surface vertical gradients are governed or influenced by aerosol production from breaking waves that can be described in terms of coastline properties and basic meteorological/oceanic parameters such as wind speed, wind direction, fetch, tides, swell, wave spectra etc.

B. Waves breaking on an offshore shallows (reef) and then advected to shore over more quiescent waters and then over land provide can be used to quantifying the production and evolution of aerosol subject to a variety of conditions via rapid in-situ, aircraft and remote sensing techniques. These data could then be extended to more complex coastal sites.

APPROACH

In order to assess the development and evolution of aerosol fields produced from breaking waves it is necessary to establish links between the breaking wave phenomena and their characteristics that affect light propagation in coastal regions. A land based site at Bellows

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Physicochemical and Optical Characterization of Aerosol Fields from Coastal Breaking Waves**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Hawaii,Department of Oceanography,1000 Pope Rd.,Honolulu,HI,96822**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Air Force Base [BAFB] with a 20m tower and laboratory, a small piloted aircraft (Seneca) and measurements including a remotely piloted light aircraft are used for in-situ observations of near surface aerosol concentrations and to characterize aerosol optical properties in the lowest 3-300 meters altitude and over small spatial scales. Our measurements include the following:

- The complete size spectra from 0.007 to 50μm was obtained by a suite of instruments operating at both dry and ambient conditions: a radial differential mobility analyzer (RDMA; 0.007<Dp<0.3μm); a laser optical particle counter (OPC, 0.1<Dp<7μm) and a dual-range external forward scattering spectrometer probe (FSSP, 0.3<Dp<20μm or 0.5<Dp<50μm). The OPC and DMA also employ thermal volatilization to infer aerosol physicochemistry (Clarke, 1991). Optical properties are measured for both fine and coarse aerosol with a 3-wavelength integrating nephelometer (TSI, Minneapolis) with an impactor size cut at 1μm (dry).
- In-situ vertical profiles of aerosol size distributions was obtained for the lowest 20m by moving instruments up and down the tower via a movable platform
- We continued periodic piloted aircraft flights over the open ocean in order to establish open ocean characteristics using our portable measurement package (single wavelength mini-nephelometer, condensation nuclei counter, FSSP, GPS, Met1 OPC's) to measure complete profiles up to 1000m.

Higher spatial and near surface vertical resolution is obtained by using our large research grade Remotely Piloted Vehicle (RPV) for coastal flights near surface and within line of sight. The RPV will include a nephelometer, a custom optical particle counter, a custom CN counter, GPS, avionics and a master computer all in a 20lb payload. It is currently being flight tested (see below) with our mininephelometer, condensation nuclei counter, optical particle counter and GPS.

We also continued our coordinated intensive field comparison of our in-situ data with the concurrent lidar measurements being separately proposed to ONR by Dr. Shiv Sharma and colleagues at UH [Measurements of Marine Boundary Layer and Water Aerosol and Water Vapor Fields with Multi-wavelength Scanning Lidar Systems]. This provided both validation and interpretation of the lidar retrievals and allow for extension of our in-situ data over the spatial aerosol fields defined by the lidar. Experiments involved both vertical and horizontal comparisons over the ocean.

WORK COMPLETED

We developed the tools and made extensive observations to describe a number of the features that influence local scattering extinction at our coastal site at BAFB. These observations are used to develop strategies for establishing more robust relationships that can be used to model variability in response to information on tide, wind, waves etc.

We have shown that our RPV is airworthy and capable of making the optical measurements of aerosol over small spatial scales required to characterize plumes lofting from breaking waves on the reef or for other environments. These will also be linked to lidar observations such that the 3-D development of such aerosol fields can be examined both remotely and in-situ. The RPV can also extend these measurements over land such that our preliminary observations of land interactions (see above) can be explored at various altitudes.

RESULTS

Our current efforts have focussed upon identifying the key environmental conditions that modulate the aerosol and its associated light scattering in a coastal environment (and, when possible, to compare these observations with lidar imagery - Dr. S. K. Sharma et al.). Our research site at BAFB is a secure operational military base located on the east side of Oahu on the north end of Waimanalo Bay. To the NE there are two small islands and just south of there a reef is exposed at low tide while further south there are shallows that can induce breaking waves under the right conditions. A deeper lagoon region tends to suppress further breaking waves until a few meters off the shoreline. This lagoon region allows the "reef" region wave produced aerosol to age and mix during transport onshore toward our tower.

Observations shown below include near surface coastal measurements that explored temporal and spatial variability studies in order to relate variability in sea-salt concentration and light extinction to environmental factors. We have also carried out the development of a remotely piloted vehicle (RPV-aircraft) for near surface measurement in the lidar path (non-eye safe) and intensive studies linking lidar measurements to the associated 3-D aerosol fields.

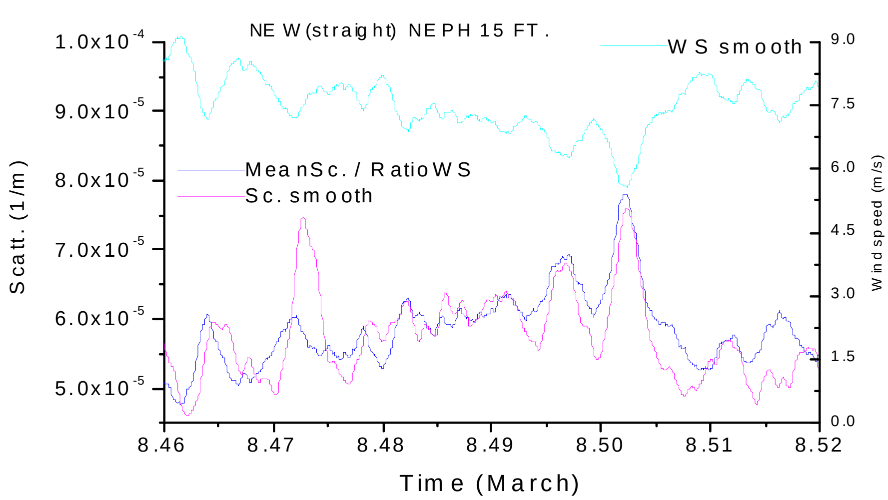
Wind direction effect

Because of the difference in offshore topography mentioned above we might expect that the effects of breaking waves will be more pronounced when winds originate from the more NE islands or reef areas. By stratifying data for periods with excursions in wind direction but only modest variation in speed (6-8m/s), we can see that for directions between about 55 and 80 deg (small islands & shallow offshore reef) enhancements of a factor of two or more in aerosol scattering at our site are common.

Dilution effect (Wind)

In contrast to the effect of increased sea-salt production over open ocean due to wind speed rising above 7-8 m/s (Woodcock, 1953; Monahan, 1968), we have identified an opposite effect for production generated from near shore breaking waves.

Fig. 1 Measured and synthesized scattering for variable wind speed

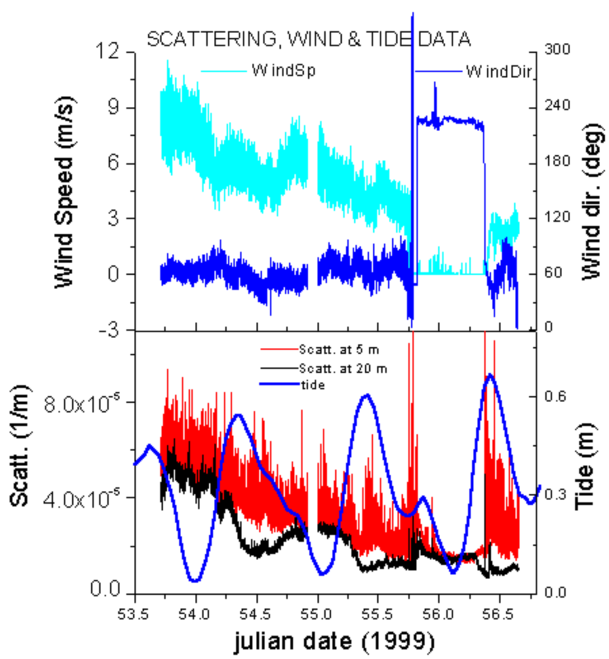


When wave breaking is occurring the effect of increasing wind is to pass more air over the source region per unit time such that concentrations of wave generated aerosol are **lower** with **increasing wind speed** (ignoring second order effects at higher wind speeds). This means that the variation in scattering contributions from coastal breaking waves should be predictable for similar conditions and could be described by a constant source term modulated by a variable wind speed. To test this we took a several hour period of fluctuations in scattering extinction during a period of breaking waves and averaged the scattering value and the average wind value. We then use the ratio of instantaneous wind to the average wind in order to describe relative fluctuations over the period. When this ratio is divided into the average scattering value a **synthesized scattering** value is obtained. An **increase** (decrease) in instantaneous wind would **decrease** (increase) this synthesized scattering in proportion to the wind speed [**dilution effect]**. If wind speed fluctuations play a significant role in modulating the measured scattering over a period then this synthesized scattering should demonstrate the same variability seen in the measured scattering. **Fig. 1** shows this synthesized scattering and measured scattering for a period of about two hours. Clearly, both the short and long term fluctuations are largely explained simply by the **dilution effect** of a variable wind speed.

Tidal effects

Under conditions of near constant wind direction the modulation in scattering at our site is also driven by tidal fluctuations. The effect on scattering will depend both on wind direction and the relative influence of near shore and outer reef effects with near shore naturally affecting lower levels on the tower more. These effects also act in concert with the effects above and can result in different influences for near shore and outer reef. As the tide drops the outer reef is more exposed and more wave energy is dissipated with waves breaking on the reef. As the tide rises more wave energy passes the reef and enhances wave break activity on the shoreline.

Fig. 2 Influence of tide on scattering at top and bottom of tower



The tide effect in conjunction with the previous effects are indicated in **Fig. 2** for a period when the

wind speed is dropping but direction is showing little change. Here the light scattering at the top and bottom of the tower are indicated along with the tide. The decreasing wind speed from a bout 9m/s to 3m/s over this period accounts for the overall decrease in scattering at both altitudes due to the open-ocean contribution decreasing. During high tide, the scattering at the top of the tower (not influenced by the shore break) shows a marked decrease in scattering and reflects the reduction in breaking waves as the reef becomes submerged. However, this effect is masked at bottom of the tower by a relative increase during these periods since the reduction in aerosol from the reef break is more than made up by an increase in the shore break. Also note the strong relative increase in scattering just before [55.75] and just after [56.5] the wind switches to offshore flow. This is the result of enhanced scattering at these low wind speeds due to the "dilution effect" discussed above. This example illustrates the potential for characterizing variations in scattering extinction in terms of various identified processes active for a specific environment.

RPV development

This April we took delivery of our custom RPV from BTA. It has about a 10ft. Wing span and 9ft length with a 65cc. Genoa motor and 18in. pusher propeller**.** Approval was granted by Hickam AFB for a two year flight program at the Bellows Air Force Base [BAFB] landing strip adjacent to our tower facility. We have carried out a number of test flights over the past two months as we gradually increase development and instrumentation capabilities. We have also built a small wind tunnel for speeds up to about 25m/s and used it for component testing. As of August 1999 we have successfully flown and operated in the following configurations at BAFB: basic airframe with receiver and controls; w/ 25lb surrogate payload – performance test; w/ BTA autopilot/altitude lock and BTA azimuth controls; w/ onboard television camera-transmitter; w/ Radiance Research nephelometer (light scattering extinction, pressure, RH); w/ self aspirating aerosol inlet; w/ GPS (Garmin). Some images from a flight on August 10, 1999 **Fig. 3.** show the nephelometer in the aircraft and the preflight start up.

Fig. 3 Flight images for August 10, 1999.

The tight circles and maneuverability of the RPV are well suited to the scale of the plumes from the breaking waves on the reef. The lidar imagery show what appears to be unexpectedly rapid vertical mixing of "reef" plume events up to 80m. It is difficult to characterize these with surface or tower measurements and they are too small to maneuver around and sample with the larger Seneca aircraft. It is the development of these and similar features that the RPV will allow us to explore in conjunction with the lidar.

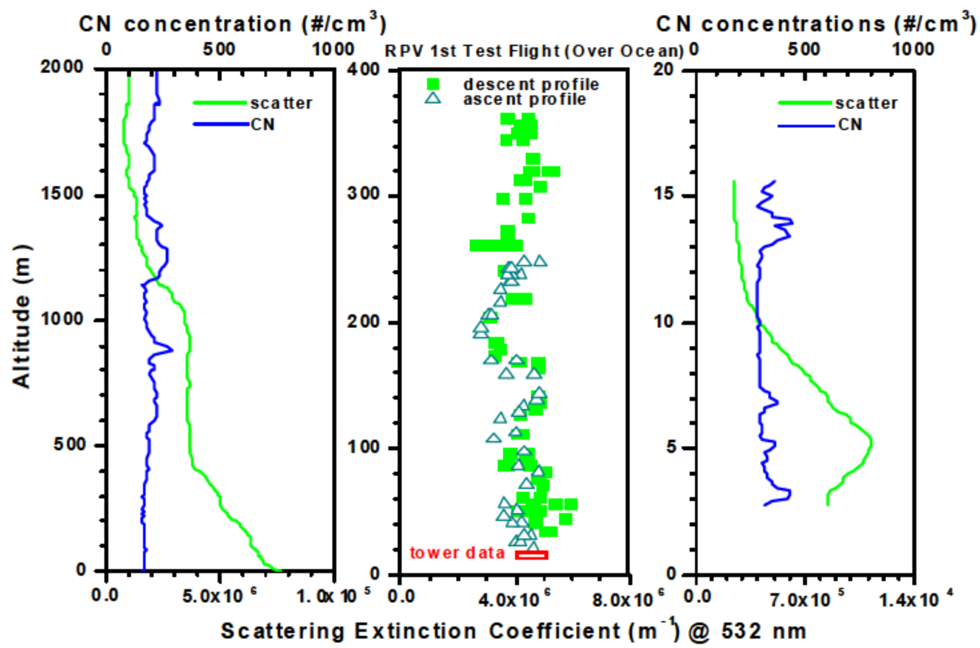
Continued instrumentation development and testing is planned to include: addition of computer and

datalogger/controller; integration of our custom miniature condensation nucleus counter (chamber and detector components donated by TSI); RH and temperature sensors; Real-time data downlink with position (over TV audio channel); ultrasound detector (Senix) for low altitude height detection (below 10m); spectral upwelling radiance measurements to get bubble/foam coverage.

Vertical Profiles

We have measured the vertical profiles of aerosol over several spatial scales from the open ocean values over the lowest kilometer(s) using our Seneca aircraft, up to a few hundred meters using our RPV aircraft and over the lowest 20m using a profiling instrument package on our tower. **Fig. 4** shows three panels that illustrate each of these measurements near BAFB on different days. The first panel shows the profile upwind of BAFB and the reef. Here low scattering above 1200 m transitions to a steady value in the mixed "cloud" layer 400-1200m and then increases steadily in a gradient toward the surface below 400m. CN show less change but tend to be higher aloft than near the surface, as we have found elsewhere.

Fig. 4 Vertical profiles from Seneca over ocean [0-2000m], RPV over coast [0-400m] and on tower [0-15m] for scattering and condensation nuclei.



The middle panel shows the two profiles made between the coast and the reef for the flight shown in **Fig. 3.** Both profiles are about 10 min apart but show very similar structure between 80 and 250m. The greater variation below 50m is probably due to inhomogeneous plumes from the breaking waves from the reef. Even so, these profile values from the first open ocean test flight of the RPV bracket the variability in scattering measured at that time at our research site (tower data) and suggest that the RPV measurements are representative. This is encouraging support of our approach to use the RPV to investigate the fast rising plumes seen in the lidar data that may not readily be observed at the tower site. The third panel is an example for another day when our instrument package was winched up the tower over a 3 min period to examine vertical variability in scattering within the lowest 20m. The 3 CN peaks (5sec data) below 7m during ascent are caused by 3 breaking shore waves. The scattering was averaged over 30s such that it smoothes over these events to reflect a more "time averaged" sense of near surface plume structure below 9m. This scale and variation is consistent with the along beach lidar structure observed.

IMPACT/APPLICATION

The results of our linking aerosol microphysics to optical properties and lidar backscatter in a coastal setting provide concurrent data on the scales and variability in the aerosol properties that dominate its optical effects. These kind of measurements can be used to model aerosol properties linked to their radiative effects. This information can also be used to validate and refine operational optical models such as NOVAM. Continued application of this approach to our data in the clean central Pacific including the coastal and breaking wave environment will should provide new inputs for regimes where the existing NOVAM model has less reliability. The linkages of aerosol physical, chemical and optical properties being explored during the current Hawaiian coastal measurements will improve modeling of boundary layer aerosol fields from breaking waves.

RELATED PROJECTS

1 - We are actively involved in coordinated activities with Dr. S. K. Sharma's Lidar project (as indicated above). This is ONR project #N000149610317 and more can be found under his filed report op68.doc.

2 - Some of our aircraft studies aboard the SENECA aircraft are being carried out with Dr. John Porter as part of our NASA grant Aircraft Radiation and Aerosol Measurements near Hawaii: Satellite Validation at the MOBY Buoy and HOTS Site (co. P.I. with J. Porter), NASA, 1/98-12-2001

REFERENCES

- Clarke, A. D. "A Thermo-optic Technique for in-situ Analysis of Size-resolved Aerosol Physicochemistry", Atmos. Env., 25A, 3/4, 635-644, 1991
- Monahan, E.C., Seaspray as a function of low elevation wind speed, J. Geophys. Res., 73, 1127-1137, 1968
- Woodcock, A.H., Salt Nuclei in marine air as a function of altitude and wind force, J. Met, 10, 362, 1953.

PRESENTATIONS

Porter, J.; B. Lienert, S.K. Sharma, T. Cooney and A. Clarke: Deriving Aerosol Properties form combined Passive and Active Measurements, in Optical Sensing of the Atmosphere, OSA Technical Digest Series, Vol. 6, pp 21-22., (1997)

S.K. Sharma, B. R. Lienert, J.N. Porter and A.D. Clarke, Scaning lidar imaging of marine aerosol fields generated by breaking waves, in Proceedings of the 19th International Laser Radar Conference-Part 2, p673-676, Annapolis (1998).

Clarke, A.D., Moore, K. and Kapustin, V; Aerosol Vertical Profiles Over The Central Pacific: Size Distributions And Scattering Extinction, Ocean Optics XIV Meeting, Kona, Hawaii, Nov 10-13, 1998.

Clarke, A.D., Submicrometer Sea-Salt In The Remote Marine Environment, European Aerosol Conference, Prague, Sept. 1999.